

PACIFIC SOUTHWEST Forest and Range Experiment Station

SPROUT REGENERATION OF YOUNG-GROWTH REDWOOD: SAMPLING METHODS COMPARED

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Sprout regeneration was studied in 1972 in a 40-year-old redwood stand on the Jackson State Forest in northern California after the stand was thinned in 1971. Two sampling techniques for estimating regeneration were compared: fixed-area quadrats and point-sampling using four basal area factors (BAF) with two edge-effect weighting procedures. Although variability of the sprout population was high, quadrat sampling provided less variation for a given number of stumps per sample than did point sampling. The 4-milacre quadrat appeared to be more efficient than other quadrats and sizes tested. Either sampling method appears reasonable from standpoints of sampling variability and amounts of time and energy expended. Quadrat sampling has the advantages of requiring, on the average, only a few stumps per quadrat, and of being widely used by foresters.

Retrieval Terms: *Sequoia sempervirens*; regeneration; restocking; sprouting potential; vegetative reproduction; sampling methods; edge effect; Jackson State Forest, California.

Redwood (*Sequoia sempervirens* D. Don. Endl.) can regenerate by sprouting. But the silvicultural and economic implications of this trait for forest managers are not understood. Managers of redwood stands need to assess the amount of regeneration that becomes established after harvest. A large proportion of redwood lumber is now coming from partially-cut stands in northern California that are less than 100 years old.

Some studies have found that redwood developed from sprouting is a major component of older young-growth stands.^{1,2,3} Other studies suggest that sprouts are not an important part of the restocking of cutover old-growth stands.^{4,5} The number and growth of sprouts has been investigated in old-growth, but not in young-growth stands.^{6,7,8}

Redwood sprouts are concentrated at the stump. The distribution of the original stand, therefore, strongly affects the location of sprout regeneration. Because sprouts have a clustered distribution, any technique for sampling them must sample stumps.

In comparing two techniques for estimating the means and variances of six mapped clump populations, I found that sampling by quadrats was more efficient than by points. Sampling by using a 4-milacre quadrat had more advantages in the dense, young-growth stands studied.

SITE AND METHODS

This study was done in 1972 on a 40-year-old, young-growth stand in the Jackson State Forest, in northern California. The original old-growth was

clearcut in 1928, and thinned in January 1971. Elevation of the site is about 800 feet with a north-east aspect and an average slope of 40 percent. The soil is classified as Mendocino and is rated as a medium-to-high site upland soil well suited for redwood.

In 1970, age of the stand at breast height ranged from 37 to 42 years and averaged 41 years. Estimates of the stand site index (base age 100 years) on the basis of age at breast height and total height of dominant redwood are 175.⁹ Stand basal area of conifer trees larger than 4.5 inches d.b.h. before thinning ranged from 367 to 425, and averaged 393 sq ft per acre. Basal area of hardwood trees larger than 4.5 inches on the plots averaged 8.3 sq ft. Total stand basal area averaged 401.3 sq ft per acre. Total number of stems (all species) larger than 4.5 inches ranged from 400 to 580 and averaged 515 per acre before thinning. The initial average diameter was 11.95 inches. Plots were randomly assigned to thinning levels. Trees were marked to leave residual stands that were 25, 50, and 75 percent of the initial stand basal area. After thinning, average diameters increased to 20.25, 17.5, and 15.7 inches for the respective residual stands.¹⁰ Because emphasis was to thin from below and concentrate tree harvest in the smaller diameter classes, all hardwoods and conifers smaller than 4.5 inches d.b.h. were removed.

All stumps and trees were mapped on six of the nine thinned 0.4-acre plots and the basic plot data was summarized (table 1). An average of 672 trees and stumps of all sizes and species were found on the six plots. Live redwood stumps averaged 435 per acre, with an average of 117 per acre less than 4.5 inches at stump height. The incidence of sprouting averaged 90.5 percent of all redwood stumps.

Preparation of the stem maps of the six thinning plots was done from angles and distances to each stump or tree from nine possible transit locations.

Each stand element (a tree or stump) was referenced to a selected corner of the plot by a pair of rectangular coordinates on a horizontal plane (fig. 1). I used quadrats that covered 100 percent of the plots and a grid of 441 point-sample points to develop means and standard deviations representative of the six plot populations.

Each stand element, represented by a single pair of coordinates, is also represented by a set of descriptive characteristics, such as species, diameter, number of clumps, and number of sprouts. The sampling rules to be tested were programed to examine the set of values associated with each spatial location. If the stand element was selected, its per-acre contribution to the sample estimate was computed.

Whether a stump is selected by a point-sample rule depends on three values: (a) the stump diameter, (b) the basal area factor (BAF), and (c) the distance from sample point to the stump center. The contribution that a stump makes per acre depends on (a) and (b) and the rule that deals with edge bias. Methods of treating edge bias in point-sampling, as described by Grosenbaugh¹¹ and Palley and O'Regan,¹² have been tested. The need to weight selected stumps is a result of the theory underlying this sampling technique, and in these small plots a high percentage of sampling points fall in zones that contain edge-influenced stumps. Sample testing cannot ignore the bias in per-acre estimates resulting from stumps near plot boundaries. Because the sample rules cannot select stumps outside the plot boundaries, methods have been devised that weight those stumps selected within the plot to compensate for this restriction.

Grosenbaugh¹¹ suggests that weights of 1, 2, and 4 be given to selected stand elements, depending on the zone in which the element is located. These zones are established as a function of the BAF and the maximum stump diameter expected on the plot. The BAF constant (k) refers to the value by which a diameter is multiplied to determine the distance in

Table 1—Redwood stumps and sprouts per acre found in mapping six 0.4-acre plots of a thinned 40-year-old redwood stand on the Jackson State Forest in northern California

Plot	Residual basal area	Redwood stumps	Clumps	Sprouts	Residual trees	Redwood stumps sprouted
	Percent					Percent
1	25	282	980	6,842	58	98.2
6	25	765	2,068	10,550	62	94.4
8	25	420	1,184	6,977	45	89.2
4	75	318	615	2,200	258	84.2
9	50	428	1,022	4,360	102	89.5
10	50	395	968	5,705	130	87.3
$\bar{X}$		434.7	1,139.5	6,105.7	109.6	90.5
SD		172.0	491.5	2,811.2	80.6	5.0

feet that a stump will be included from a sample point. Constants used in this study were:

BAF	Constant (k)
80	0.9723
40	1.375
20	1.944
10	2.750

Nine zones were established in a square plot with a BAF constant of 1.0 and 20.0-inch stump (*fig. 2*). All stumps in corner zones 1, 3, 7, and 9 were given a weight of 4, and could be selected only if the sample point fell in the shaded quarter of the k-circle shown for tree A. Stumps in zones 2, 4, 6, and 8 were given a weight of 2, and were selected if the sample point fell in the shaded one-half circle of tree B. A stump whose coordinates indicated it was in zone 5 received a weight of 1, and was selected by any point within the full k-circle, tree C.

Palley and O'Regan¹² weighted stand elements that are selected by point-sample by the reciprocal of the fraction of the k-circle that falls within the plot boundaries. For example, tree A has 0.80 of the expanded circle within the plot (*fig. 2*). This tree, if selected from any point within this circle and inside the plot boundary, is weighted by the value 1.25. Tree C, with its entire k-circle within the 0.4-acre plot, has a weight of 1.0.

The estimate of the number of clumps per acre is a function of the number of clumps on a stump, the stump diameter, and the BAF. The sample points are located and each stand element is examined to determine if the sample point falls within the k-circle associated with the BAF and stump diameter. If, in this instance, the stump is selected, the number of clumps per acre associated with stumps of that diameter are computed as:

$$\text{Clumps per acre} = \frac{\text{BAF}}{0.005454} \times \frac{1.0}{\text{Dia}^2} \times \text{Clumps}$$

Then, depending on the weighting rule, clumps per acre is multiplied by the appropriate weight, as described earlier. The sum of clumps per acre for each of the individual stumps selected from the sample point gives the total estimate of clumps per acre.

In the point-sample tests made of these six plots, a grid of 21 by 21 points spaced at 6-foot intervals was established in each 132-foot square plot. The number of clumps per acre was computed for each of the 441 grid points per plot to determine estimates of the population mean and standard deviation. Separate estimates were made for the four BAF's tested in each of the two weighting systems (*table 2*).

Tests of fixed-area quadrats have been based on four sets of square quadrats of 1/4, 1, 4, and

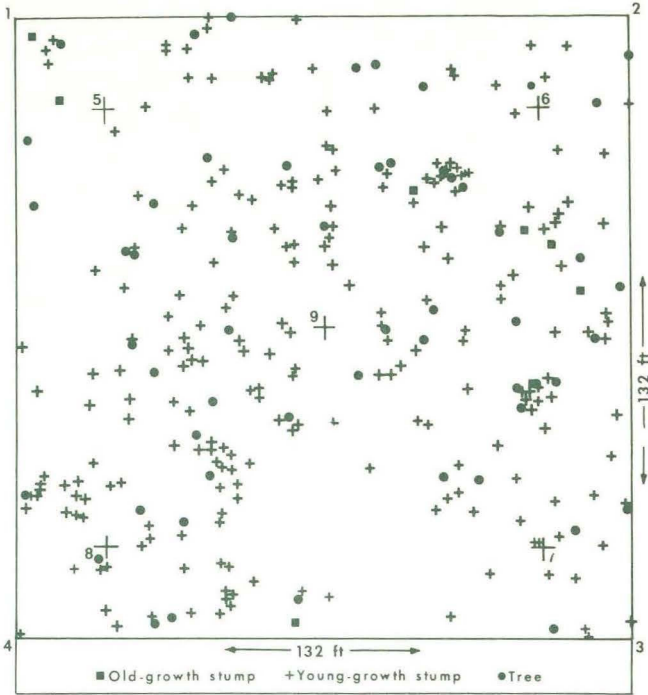


Figure 1—The stem and stump map of plot 10, showing spatial arrangement of the stand elements, and the nine possible transit locations at the corners and center of the 0.4- and 0.2-acre plots.

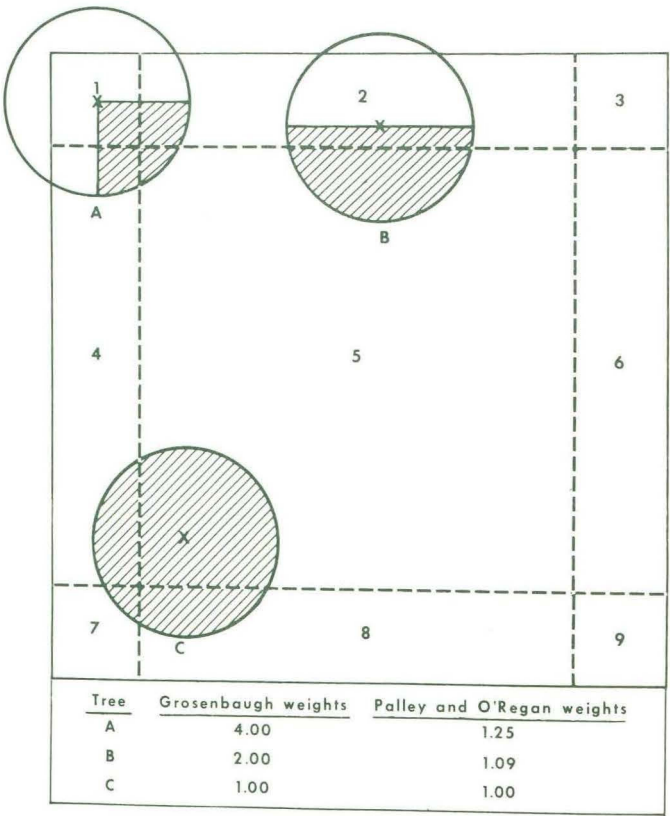


Figure 2—Diagram of the weighing zones of the Grosenbaugh system with a 20-inch tree and K-factor of 1.00 to establish a 20-foot wide border zone.

Table 2—Two weighting systems for means and standard deviations of redwood clumps per acre of 441 point samples in each 0.4-acre plot on the Jackson State Forest in northern California

BAF ¹	Plot number											
	1		6		8		4		9		10	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Grosenbaugh System												
80	1085.5	1314.7	2227.4	2944.8	1261.4	1412.2	749.8	1876.8	918.5	1222.9	1120.9	2353.3
40	1049.8	1084.1	2277.4	2758.4	1215.0	1106.0	716.1	1255.4	1029.4	1298.7	991.9	1501.2
20	1077.3	1112.9	2260.3	2366.7	1239.4	1110.9	658.8	931.6	1058.5	1268.6	1006.0	1259.4
10	1063.0	966.7	2306.2	2498.1	1279.9	1276.3	697.7	859.9	1148.8	1582.0	1035.3	1350.1
Palley and O'Regan System												
80	1014.0	1064.6	2068.7	2355.0	1204.1	1262.1	653.6	1040.1	938.3	1125.6	1166.2	2444.5
40	997.3	811.5	2127.1	2192.4	1160.1	901.8	636.5	819.9	989.5	983.6	1005.8	1441.3
20	992.2	725.0	2144.3	1837.0	1156.9	721.9	637.9	620.7	1019.7	1011.4	995.4	1097.1
10	980.7	554.0	2125.9	1579.8	1164.7	641.9	620.7	486.6	1011.3	815.6	982.3	824.0

¹BAF = basal area factor.

16 milacres. Square quadrats of these sizes fit into the 0.4-acre plots so that sets of 1600, 400, 100, and 25 quadrats result in 100 percent samples of each plot. Locating each stand element with the pair of coordinates as its center means that the stand element can be in only one quadrat of each set. Areal samples of this type do not have the same problem of weighting to deal with the edge effect. Each stand element is either in or out of a quadrat, and only its position determines its weight: If in the plot a weight of 1, if outside the plot a weight of 0. A random location of a fixed area quadrat, the area of which extends beyond the stand boundaries, however, requires adjustment for edge-bias in a manner similar to that described for the Palley and O'Regan method.¹² Estimates of per-acre values of quadrats are simply the average of the sample times the number of quadrats per acre. Estimates of the means and standard deviations of the 100 percent samples of four quadrat sizes tested are summarized (table 3).

RESULTS AND DISCUSSION

Tests of the computer sampling methods are restricted to the counts of sprout clumps rather than the sprout estimates. During the first few years after harvest, the clumps are often dense and an accurate count of individual sprouts is difficult and time consuming. I believe that a count of the number of distinct clumps on these stumps gives a more realistic indication of the crop tree potential of the sprouting. This approach differs somewhat from that of the California Forest Practice Rules, which allow one sprout per foot of stump diameter up to a maximum of six sprouts.

Results of our study indicated an average of 2.62 clumps per stump and an average of 5.36 sprouts per clump (table 1). The crop tree rule adopted means that about 81 percent of the sprouts will not develop, and that 1139.5 sprouts per acre will develop to the point of being considered as crop trees. Number of clumps showed a linear correlation to the number of redwood stumps (table 1). This limited example had a correlation coefficient of 0.897, which is considered highly significant by Snedecor.¹³ Plot 4, with a residual basal area of 75 percent, still had 258 trees and the lowest number of clumps, but these uncut trees would provide ample sprout regeneration when harvested. The stand of plot 6 had many stems smaller than 4.5 inches and these small trees contributed heavily to the clump population.

Percentage of sprouting appears to be weakly correlated with the residual basal area. An analysis of sprouting by diameter class did not indicate that the percentage of sprouted stumps is related to diameter. In analysis of variance tests on the means of the four basal area factors in each weighting system, F-levels computed indicated that in neither system were differences between the estimated means of the 441 sample points significant. The choice of BAF was not an important consideration in the estimation of the clump means; in effect, any of the basal area factors tested gave an acceptable estimate of the plot mean. A summary of the results of the point sample tests showed the narrow range of the point sample estimates of the number of clumps per acre (table 2). The standard deviations of the 441 observations of the Grosenbaugh¹¹ system demonstrated a slight drop with decreasing BAF, except for plots 4 and 10. In these two plots, the standard deviation decreased sharply as the BAF dropped. As the BAF dropped from 80 to 10

Table 3 — Mean and standard deviations of sprout clumps per acre, by quadrat size, for 100 percent samples of six plots on the Jackson State forest in northern California

Plot	Sprout clumps $\bar{X}$	Quadrat size (milacres)							
		1/4		1		4		16	
		SD	Stocking Pct. ¹	SD	Stocking Pct.	SD	Stocking Pct.	SD	Stocking Pct.
1	980	4176	6.7	2249	24.0	1170	61.0	712	84.0
6	2068	5762	15.9	3176	45.5	2067	82.0	1444	100.0
8	1184	4436	8.5	2524	29.7	1285	65.0	657	96.0
4	615	2688	7.1	1364	23.5	744	57.0	492	92.0
9	1022	3864	9.1	2151	28.7	1040	71.0	563	100.0
10	968	3828	8.6	2029	28.5	1164	62.0	710	92.0
$\bar{X}$	1139.5	4125.7	9.3	2248.8	30.0	1245.0	66.3	763.0	94.0
SD	491.5	1000.1	3.4	596.0	8.0	443.3	9.0	344.6	6.1

¹Stocking percent refers to the number of quadrats stocked with redwood stumps.

for the Palley and O'Regan¹² test, there was an apparent sharp reduction of the standard deviations. This reduction was the result of an increasing number of redwood stumps per sample (table 4). For example, 6.4 times as many redwood stumps were required for the Palley and O'Regan BAF of 10 as for the BAF of 80.

Differences in the number of stumps per sample point of the two methods for a given BAF resulted from the weighting methods used to deal with edge bias. The number of stumps examined for a given BAF was always greater for the Palley and O'Regan system. Because a stump located in the side or corner zones must fall within the one-quarter or one-half circle to be selected by the Grosenbaugh¹¹ system, many stumps were ignored that the Palley and O'Regan¹² system must accept. With large plots or cut blocks, where the number of sample points near the edge are not an important variable, little difference in the number of stumps of the two systems would be expected. As the BAF decreases, the average number of stumps per point increases, and the increase of the Palley and O'Regan¹² system is more rapid. For example, a BAF of 80 showed a difference of only 0.41 stumps per point, but for a BAF of 10, this difference increased to 10.8 stumps.

The average number of stumps per sample point affected the standard deviations of the point-sample estimates of the number of clumps (fig. 3).¹⁴ Decreased standard deviation occurred as the number of stumps per sample increased. The Grosenbaugh¹¹ results, however, do not show a well-defined consistent drop of the standard deviations. In both systems there appears to be a break of the trend at about BAF 40. Despite a two-to-three times increase in the number of stumps, only relatively small decreases of the sample standard deviations occur.

Sampling with the quadrats where the sample set is a 100 percent sample, results in estimates of the

mean number of clumps that equal the population values (table 1). As quadrat size increased, however, the standard deviation decreased, and the percentage of stocked quadrats increased (table 3). All six plots showed a nearly parallel increase in stocking as quadrat size increased. On the average, stocking improved 3.3 times as quadrat size increased from 1/4 to 1 milacre, but only 1.4 times in the increase from 4 to 16 milacres. In the 1-milacre quadrats, nearly 7 of 10 quadrats did not include a redwood stump, although only 3 of 10 of the 4-milacre quadrats were not stocked. The amount of time to locate and establish a quadrat is about the same regardless of size, so return on the labor is much higher for the 4-milacre quadrats.

Reduction of standard deviations with increasing quadrat size (fig. 4) indicated a sharp drop in standard deviations between 1/4 and 1 milacre. By increasing quadrat size to 4 milacres, the standard deviations were nearly cut by one-half. Expanding to 16 milacres, however, really did not materially improve the estimate of the standard deviation.

The trend of sample standard deviations plotted over the number of stumps (fig. 3) showed a sharp drop between 1- and 4-milacre quadrats. The 1-milacre quadrats have standard deviations that are unacceptable. By increasing the size to 4-milacres, this variability is much reduced. For all six plots the curves indicate that, given the number of stumps per sample, the 4-milacre quadrat is more efficient than any BAF tested. The average standard deviations of the 4-milacre samples appear to be similar in magnitude to those with 40 as a BAF, but are achieved with a much lower number of stumps per sample. Quadrat sampling generally has a lower level of variation for a given number of stumps per sample (fig. 3).

A statistic for comparing the relative merit of the sampling techniques is the standard error of the mean ($S\bar{y}$). This measure is used to determine the

Table 4—Redwood stumps examined on each point-sample or quadrat established in six mapped plots of thinned 40-year-old redwood on the Jackson State Forest in northern California

Plot	Grosenbaugh BAF ¹				Palley and O'Regan BAF				Quadrat (milacres)			
	80	40	20	10	80	40	20	10	1/4	1	4	16
1	1.96	3.10	5.03	7.15	2.31	4.30	7.88	14.20	0.07	0.28	1.13	4.52
6	3.80	6.00	9.18	12.15	4.29	8.03	14.89	26.76	.19	.76	3.06	12.28
8	3.64	6.14	9.96	12.81	4.11	7.84	14.45	25.97	.10	.42	1.68	6.72
4	2.08	3.65	5.33	6.87	2.45	4.71	8.92	16.25	.08	.32	1.27	5.08
9	3.05	4.56	7.56	10.75	3.50	6.64	12.14	22.12	.11	.43	1.71	6.80
10	2.20	3.77	5.67	7.62	2.54	4.87	9.22	16.86	.10	.39	1.58	6.32
Average	2.79	4.54	7.12	9.56	3.20	6.07	11.25	20.36	0.11	0.44	1.76	7.04

¹BAF = basal area factor.

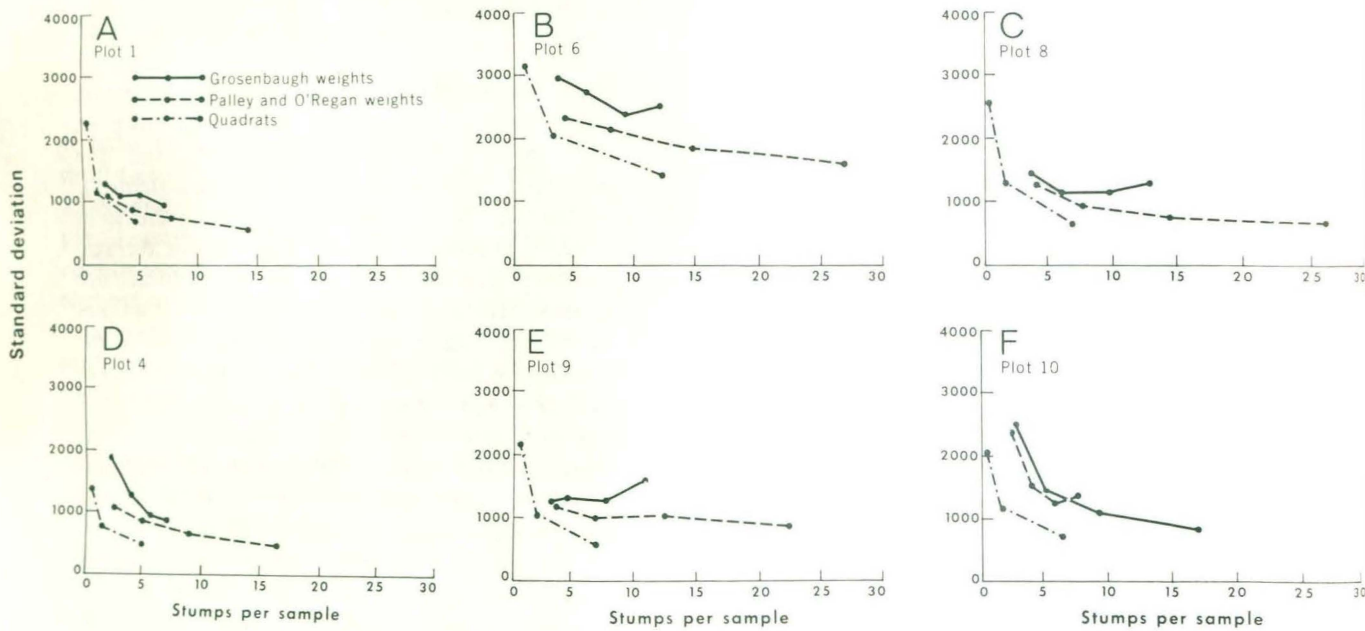


Figure 3—The sample standard deviations of the clumps per acre as number of redwood stumps per sample increases with basal factor and quadrat size.

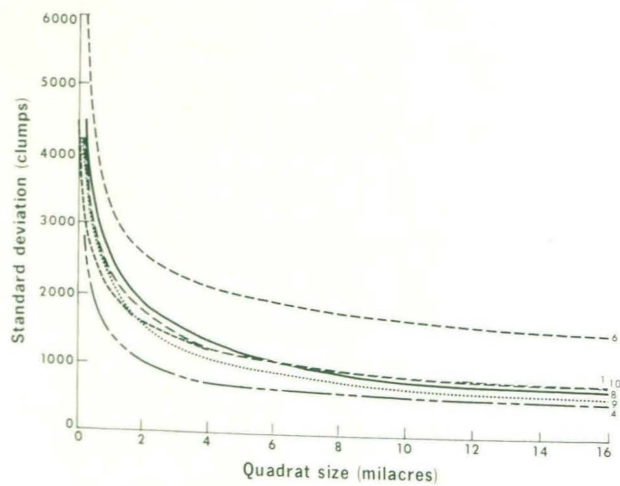


Figure 4—Effect of increasing quadrat size on the standard deviations of clumps per acre.

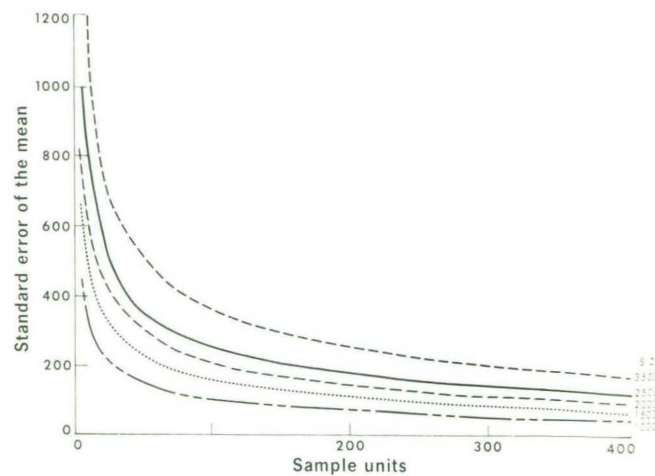


Figure 5—The effect of increasing the number of sample units on the standard error of the mean for selected sample standard deviations.

Table 5—Estimated number of sample units required for the sample estimate to be within ± 20 percent of the population mean (at the 95 percent level of confidence), by basal area factor, for the six plots

Plot	Grosenbaugh BAF ¹				Palley and O'Regan BAF				Quadrat (milacres)	
	80	40	20	10	80	40	20	10	1	4
1	171.1	117.5	123.8	93.4	113.3	65.8	52.6	30.7	505.8	136.9
6	194.7	170.9	125.8	84.8	124.5	107.9	75.8	56.1	226.5	95.9
8	137.1	84.1	84.8	112.1	109.5	55.9	35.8	28.3	436.4	113.1
4	894.4	400.2	220.4	187.7	274.7	170.7	97.8	60.1	472.9	140.6
9	137.5	155.1	147.9	230.1	115.8	88.4	93.5	60.8	425.4	99.4
10	567.6	231.0	162.6	186.8	612.5	213.4	123.4	69.6	421.9	138.9
Average	350.4	193.1	144.2	149.1	225.2	117.0	79.9	48.9	414.82	120.8

¹BAF = basal area factor

precision of the estimates of the sample sets. It is possible to determine the $S\bar{y}$ from the standard deviation shown in *tables 2 and 4* in the following manner:

$$S\bar{y} = SD / \sqrt{n}$$

in which

$S\bar{y}$ = The standard error of the mean

SD = Standard deviations of the basic sample sets

n = Number of sample points or quadrats

As sample size increases, the value of $S\bar{y}$ changes (*fig. 5*). For each standard deviation of the basic sample sets, it is possible to see how precision improves as sample size increases. The standard error is used to establish confidence limits and determine the correct number of samples necessary to reach a specified level of sampling precision, given the variability of the sprout population.

Freese¹⁵ describes a method of calculating the number of samples to meet a set of standards desired by the sampler:

$$n = \frac{t^2 SD^2}{E^2}$$

in which

n = The required number of samples

t = The t-table value for n - 1 degrees of freedom and probability

SD = Standard deviation of population

E = Limits about the estimated mean

An example of determining the number of sample units required to be 95 percent confident that the sample estimate is within ± 20 percent of the

population is shown in *table 5*. If we combine the number of samples (*table 5*) and the number of stumps per sample (*table 4*), we can indicate the amount of work required to achieve this level of confidence.

CONCLUSIONS

Extensive sampling in the mapped plots with either the point-samples or fixed-area quadrats estimated sample means that were similar to the actual values of the plot populations of clumps. Use of a point-sample device to select stumps has the advantage of selecting the sample where the sprout clumps occur. If costs of sampling are a function of number of samples and number of stumps per sample, however, then the 4-milacre quadrat costs less for a selected level of variation and confidence.

Variability of the sprout population in these six plots of thinned young-growth redwood is high. Any sampling scheme needs to recognize that to deal with this level of variability and also meet stringent levels of confidence will be costly in terms of the number of sample units required. In this stand with 400 sq ft of basal area over 4.5 inches, however, a high level of clump development on the stumps suggests the probability that the number of sprout clumps will exceed the minimum regeneration density acceptable in California of 300 stems per acre. The average of the six plots in this study was almost 1200 clumps per acre.

Differences between the two systems for treating edge bias in the point samples become more apparent as the BAF decreases from 80 to 10. The sample means do not appear to be different, but the smaller standard deviation associated with the Palley and O'Regan¹² weighting system is made at the expense of many more redwood stumps per sample point. In these plots it seems that the

40 BAF provides a reasonable balance between the standard deviations and the number of stumps per sample. For field application the Grosenbaugh¹¹ system is most easily used; the weights and selection criteria are clearly set forth. The average number of stumps per sample, however, is better exemplified by the Palley and O'Regan system.¹² In these small plots, the corner and size zones of the Grosenbaugh¹¹ system occupy a large percentage of the total plot area and result in a somewhat distorted view of the average number of stumps per plot. This difference amplifies as the BAF decreases, with a difference between the average stumps per point at BAF 80 of only 0.4, and this increases to 10.8 stumps at BAF 10. In large blocks where most sample points would have no edge trees, there would be no difference between systems in the average number of stumps per sample point.

The 4-milacre quadrat appears most efficient in these dense young-growth stands. Milacre quadrats are not a reasonable sample unit in these stands because the spatial variability of the stumps results in too much sample variability. Undoubtedly, this results from an average of nearly 70 percent of the milacre quadrats being nonstocked. Quadrats larger than 4-milacres in this study show a low return; the smaller standard deviation for the amount of effort expended does not seem warranted.

Either sampling method—the point-sample using a 40 BAF and the Grosenbaugh¹¹ weighting procedure, or 4-milacre quadrats—appears to be reasonable from the standpoints of sampling variability and amount of work. Quadrat sampling has the advantages of requiring, on the average, only a few stumps per quadrat, and of being widely used by foresters.

NOTES

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⁹Lindquist, James L., and Marshall N. Palley. 1961. *Site curves for young-growth coastal redwoods*. Calif. For. and Forest Prod. 29, 4 p., Berkeley, Calif.

¹⁰Data on file at Pacific Southwest Forest and Range Experiment Station, Arcata, Calif.

¹¹Grosenbaugh, L. R. 1958. *Point-sampling and line-sampling: probability theory, geometric implications, synthesis*. USDA Forest Serv. Occas. Paper 160, 33 p. Southern Forest Exp. Stn., New Orleans, La.

¹²Palley, Marshall N., and William G. O'Regan. 1961. *A computer technique for the study of forest sampling methods*. Forest Sci. 7:282-294.

¹³Snedecor, George W. 1956. *Statistical Methods*. 534 p. Iowa State College Press, Ames, Iowa.

¹⁴Standard deviations of the 1/4-milacre quadrats are not plotted in figure 3 because of limitations of the scale.

¹⁵Freese, Frank. 1967. *Elementary Statistical Methods for Foresters*. U.S. Dep. Agric., Agric. Handb. 317. 87 p.

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